UR-1599
ER/40685/944
December 1999

arXiv:hep-ph/0001139v1 14 Jan 2000

BFKL Monte Carlo for Dijet Production at Hadron Colliders*

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The production of jet pairs at large rapidity difference at hadron colliders is potentially sensitive to BFKL physics. We present the results of a BFKL Monte Carlo calculation of dijets at the Tevatron. The Monte Carlo incorporates kinematic effects that are absent in analytic BFKL calculations; these effects significantly modify the behavior of dijet cross sections.

1. MONTE CARLO APPROACH TO BFKL

Fixed-order QCD perturbation theory fails in some asymptotic regimes where large logarithms multiply the coupling constant. In those regimes resummation of the perturbation series to all orders is necessary to describe many high-energy processes. The Balitsky-Fadin-Kuraev-Lipatov (BFKL) equation [1] performs such a resummation for virtual and real soft gluon emissions in such processes as dijet production at large rapidity difference in hadron-hadron collisions. BFKL resummation gives [2] a subprocess cross section that increases with rapidity difference as $\hat{\sigma} \sim \exp(\lambda\Delta)$, where Δ is the rapidity difference of the two jets with comparable transverse momenta p_{T1} and p_{T2}.

Experimental studies of these processes have recently begun at the Tevatron $p\bar{p}$ and HERA ep colliders. Tests so far have been inconclusive; the data tend to lie between fixed-order QCD and analytic BFKL predictions. However the applicability of analytic BFKL solutions is limited by the fact that they implicitly contain integrations over arbitrary numbers of emitted gluons with arbitrarily large transverse momentum: there are no kinematic constraints included. Furthermore, the implicit sum over emitted gluons leaves only leading-order kinematics, including only the momenta of the 'external' particles. The absence of kinematic constraints and energy-momentum conservation cannot, of course, be reproduced in experiments. While the effects of such constraints are in principle sub-leading, in fact they can be substantial and should be included in predictions to be compared with experimental results.

The solution is to unfold the implicit sum over gluons and to implement the result in a Monte Carlo event generator [3, 4]. This is achieved as follows. The BFKL equation contains separate integrals over real and virtual emitted gluons. We can reorganize the equation by combining the 'unresolved' real emissions — those with transverse momenta below some minimum value (chosen to be small compared to the momentum threshold for measured jets) — with the virtual emissions. Schematically, we have

$$\int_{virtual} + \int_{real} = \int_{virtual+real,unres.} + \int_{real,res.} \qquad (1)$$

We perform the integration over virtual and unresolved real emissions analytically. The integral containing the resolvable real emissions is left explicit.

We then solve by iteration, and we obtain a differential cross section that contains a sum over emitted gluons along with the appropriate phase space factors. In addition, we obtain an overall form factor due to virtual and unresolved emissions. The subprocess cross section is

$$d\hat{\sigma} = d\hat{\sigma}_0 \times \sum_{n\geq 0} f_n \qquad (2)$$

where f_n is the iterated solution for n real gluons emitted and contains the overall form factor. It is then straightforward to implement the result in a Monte Carlo event generator. Because emitted real (resolved) gluons appear explicitly, conservation of momentum and energy, as well as evaluation of parton distributions, is based on exact kinematics for each event. In addition, we include the running of the strong coupling constant. See [3] for further details.

2. DIJET PRODUCTION AT HADRON COLLIDERS

At hadron colliders, the BFKL increase in the dijet subprocess cross section with rapidity difference Δ is

*Presented at the Fermilab Run II Workshop, QCD and Weak Boson Physics, June 3–4, 1999.

†Work supported in part by the U.S. Department of Energy, under grant DE-FG02-91ER40685 and by the U.S. National Science Foundation, under grants PHY-9600155 and PHY-9400059.

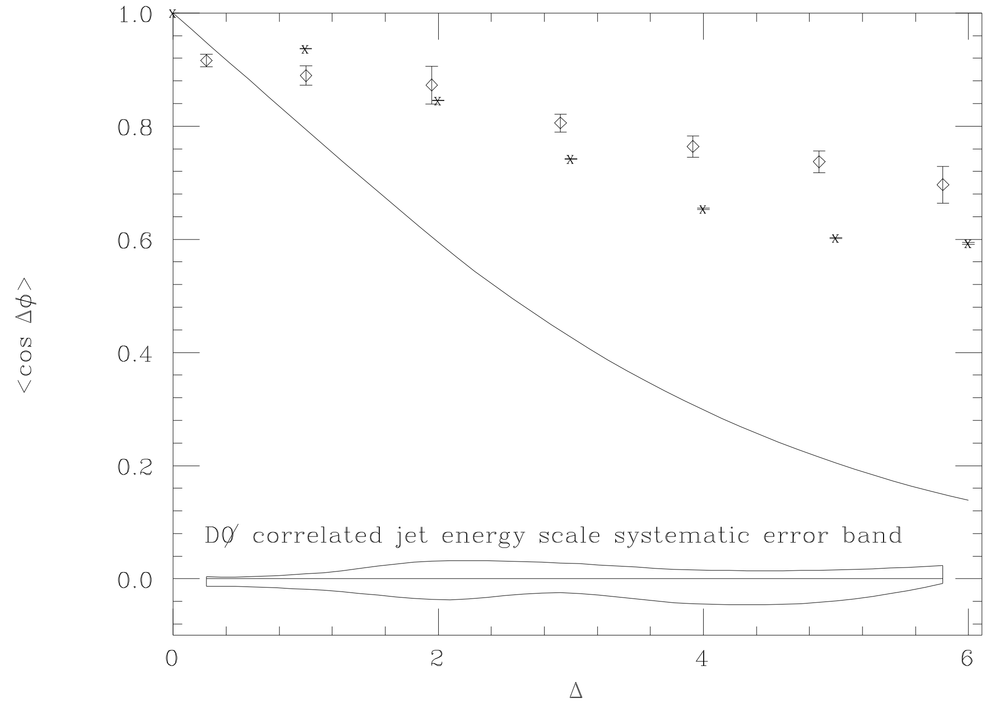

Figure 1. The azimuthal angle decorrelation in dijet production at the Tevatron as a function of dijet rapidity difference Δ, for jet transverse momentum $p_T > 20$ GeV. The analytic BFKL solution is shown as a solid curve and a preliminary DØ measurement [6] is shown as diamonds. Error bars represent statistical and uncorrelated systematic errors; correlated jet energy scale systematics are shown as an error band.

unfortunately washed out by the falling parton distribution functions (pdfs). As a result, the BFKL prediction for the total cross section is simply a less steep falloff than obtained in fixed-order QCD, and tests of this prediction are sensitive to pdf uncertainties. A more robust pediction is obtained by noting that the emitted gluons give rise to a decorrelation in azimuth between the two leading jets.[5, 3] This decorrelation becomes stronger as Δ increases and more gluons are emitted. In lowest order in QCD, in contrast, the jets are back-to-back in azimuth and the (subprocess) cross section is constant, independent of Δ.

This azimuthal decorrelation is illustrated in Figure 1 for dijet production at the Tevatron $p\bar{p}$ collider [3], with center of mass energy 1.8 TeV and jet transverse momentum $p_T > 20$ GeV. The azimuthal angle difference $\Delta\phi$ is defined such that $\cos\Delta\phi = 1$ for back-to-back jets. The solid line shows the analytic BFKl prediction. The BFKL Monte Carlo prediction is shown as crosses. We see that the kinematic constraints result in a weaker decorrelation due to suppression of emitted gluons, and we obtain improved agreement with preliminary measurements by the DØ collaboration [6], shown as diamonds in the figure.

In addition to studying the azimuthal decorrelation, one can look for the BFKL rise in dijet cross section with rapidity difference by considering ratios of cross sections at different center of mass energies at fixed Δ. The idea is to cancel the pdf dependence, leaving the pure BFKL effect. This turns out to be rather tricky [8], because the desired cancellations occur only at lowest order. Therefore we consider the ratio

$$R_{12} = \frac{d\sigma(\sqrt{s}_1, \Delta_1)}{d\sigma(\sqrt{s}_2, \Delta_2)} \qquad (3)$$

with Δ_2 defined such that $R_{12} = 1$ in QCD lowest-order. the result is shown in Figure 2, and we see that the kinematic constraints strongly affect the predicted behavior, not only quantitatively but sometimes qualitatively as well. More details can be found in [8].

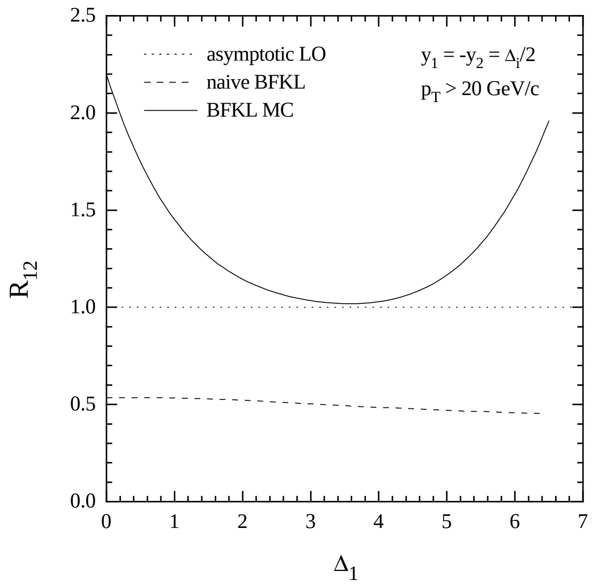

Figure 2. The ratio R_{12} of the dijet cross sections at the two collider energies $\sqrt{s}_1 = 630$ GeV and $\sqrt{s}_2 = 1800$ GeV, as defined in the text. The curves are: (i) the BFKL MC predictions (solid curve), (ii) the 'naive' BFKL prediction (dashed curve), and (iii) the asymptotic QCD leading-order prediction (dotted curve) $R_{12} = 1$.

3. CONCLUSIONS

In summary, we have developed a BFKL Monte Carlo event generator that allows us to include the subleading effects such as kinematic constraints and running of α_s. We have applied this Monte Carlo to dijet production at large rapidity separation at the Tevatron. We found that kinematic constraints, though nominally subleading, can be very important. In particular they lead to suppression of gluon emission, which in turn suppresses some of the behavior that is considered to be characteristic of BFKL physics. It is clear therefore that reliable BFKL tests can only be performed using predictions that incorporate kinematic constraints.

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